SCIENTIFIC INVESTIGATION AND INQUIRY

B.1. Broad Concept: Scientific progress is made by asking relevant questions and conducting careful investigations. As a basis for understanding this concept, and to address the content in this grade, students should develop their own questions and perform investigations.

Students:

1. Know the elements of scientific methodology (identification of a problem, hypothesis formulation and prediction, performance of experimental tests, analysis of data, falsification, developing conclusions, reporting results) and be able to use a sequence of those elements to solve a problem or test a hypothesis. Also, understand the limitations of any single scientific method (sequence of elements) in solving problems.
2. Know that scientists cannot always control all conditions to obtain evidence, and when they are unable to do so for ethical or practical reasons, they try to observe as wide a range of natural occurrences as possible so as to be able to discern patterns.
3. Recognize the cumulative nature of scientific evidence.
4. Recognize the use and limitations of models and theories as scientific representations of reality.
5. Distinguish between a conjecture (guess), a hypothesis, and a theory as these terms are used in science.
6. Plan and conduct scientific investigations to explore new phenomena, to check on previous results, to verify or falsify the prediction of a theory, and to use a crucial experiment to discriminate between competing theories.
7. Use hypotheses to choose what data to pay attention to and what additional data to seek, and to guide the interpretation of the data.
8. Identify and communicate the sources of error (random and systematic) inherent in an experiment.
9. Identify discrepant results and possible sources of error or uncontrolled conditions.
10. Select and use appropriate tools and technology to perform tests, collect data, analyze relationships, and display data. (The focus is on manual graphing, interpreting graphs, and mastery of metric measurements and units, with supplementary use of computers and electronic data gathering when appropriate.)
11. Formulate and revise explanations using logic and evidence.
12. Analyze situations and solve problems that require combining concepts from more than one topic area of science and applying these concepts.
13. Apply mathematical relationships involving linear and quadratic equations, simple trigonometric relationships, exponential growth and decay laws, and logarithmic relationships to scientific situations.
14. Observe natural phenomena and analyze their location, sequence, or time intervals (e.g., relative ages of rocks and succession of species in an ecosystem).
15. Explain that science discoveries can have both positive and negative implications, involve different decisions regarding ethics and allocation of resources (e.g., organ transplants, stem cell research, forest management, and land use).
16. Recognize and deal with the implications of statistical variability in experiments, and explain the need for controls in experiments.

SCIENTIFIC INVESTIGATION AND INQUIRY (CONTINUED)	
Examples	*Students construct an idea web of the disciplines that research evidence for evolution: geology, paleontology, molecular biology, etc. They draw numerous lines between disciplines to show how one reinforces the other (B.1.1).*
	Students research the history of treatments for a particular disease, such as epilepsy, pneumonia, or HIV (B.1.3).
	Students compare models of plant and animal cells with microscope slides (or images from the Internet) and discuss the pros and cons of models and their use as a tool in science (B.1.4).
	Students investigate the effectiveness of common household cleaners on bacterial growth. They devise an experiment to test how much of the cleaner is actually necessary for disinfection (B.1.6).
	Students hypothesize and then determine how different kinds of plants respond to various environmental stimuli (B.1.7).
	Students study the effect of temperature on photosynthetic rates of duckweed, as well as factors that affect the heart rate of daphnia and the behavior of pill bugs (B.1.10).
	Students compare and contrast the designs of different sports, and explain the differences and similarities in terms of the varying physiological demands of different sports (B.1.12).
	Students create a mathematical model for the travel of seeds. They begin with a small garden, research the number of seeds the plants can produce, and extrapolate the spread of the plant over 10, 100, and 1,000 years (B.1.13).
	Students examine the life cycle of a native DC cicada at the present moment in time (B.1.14).

CHEMISTRY OF LIVING THINGS

B.2. Broad Concept: Living things are made of atoms bonded together to form molecules, some of the most important of which are large and contain carbon (i.e., "organic" compounds). As a basis for understanding this concept,

Students:

1. Describe basic atomic structure using simplified Bohr diagrams to understand the basis of chemical bonding in covalent and ionic bonds.
2. Describe the structure and unique properties of water and its importance to living things.
3. Describe the central role of carbon in the chemistry of living things because of its ability to combine in many ways with itself and other elements.
4. Know that living things are made of molecules largely consisting of carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur.
5. Know that living things have many different kinds of molecules, including small ones such as water; midsize ones such as sugars, amino acids, and nucleotides; and large ones such as starches, proteins, and DNA.

CHEMISTRY OF LIVING THINGS (CONTINUED)

6. Observe and explain the role of enzymatic catalysis in biochemical processes.

7. Explain the hierarchical organization of living things from least complex to most complex (subatomic, atomic, molecular, cellular, tissue, organs, organ system, organism, population, community, ecosystem, and biosphere).

Examples

Students build models of carbon-based molecules such as methane (CH_4) and glucose ($C_6H_{12}O_6$). They explain the variety of bonds carbon is able to make and explain how the addition of other elements changes the physical and chemical characteristics of the carbon-based molecule (B.2.3).

Students examine the chemical bonds in amino acids and DNA. They hypothesize about the smaller molecules and simpler reactions that could have occurred before these more complex chemicals were formed (B.2.4).

Students research the basic chemicals necessary for life and find similarities among living organisms (B.2.5).

Students view computer animations of enzymes in biochemical pathways, and then set up an enzyme experiment by placing meat tenderizer on deli ham, or by dissolving lactase pills in plain yogurt. They record the scent and sight of the food product after a period of time (B.2.6).

CELL BIOLOGY

B.3. Broad Concept: All living things are composed of cells. All the fundamental life processes of a cell are either chemical reactions or molecular interactions. As a basis for understanding this concept,

Students:

1. Compare and contrast the general anatomy and constituents of prokaryotic and eukaryotic cells and their distinguishing features: Prokaryotic cells do not have a nucleus, and eukaryotic cells do. Know that prokaryotic organisms are classified in the Eubacteria and Archaebacteria Kingdoms and that organisms in the other four kingdoms have eukaryotic cells.

2. Understand the function of cellular organelles and how the organelles work together in cellular activities (e.g., enzyme secretion from the pancreas).

3. Observe and describe that within the cell are specialized parts for the transport of materials, energy capture and release, waste disposal, and motion of the whole cell or of its parts.

4. Describe the organelles that plant and animal cells have in common (e.g., ribosomes, golgi bodies, endoplasmic reticulum) and some that differ (e.g., only plant cells have chloroplasts and cell walls).

5. Demonstrate and explain that cell membranes act as highly selective permeable barriers to penetration of substances by diffusion or active transport.

6. Explain that some structures in the eukaryotic cell, such as mitochondria, and in plants, such as chloroplasts, have apparently evolved by *endosymbiosis* (one organism living inside another, to the advantage of both) with early prokaryotes.

7. Describe that the work of the cell is carried out by structures made up of many different types of large (macro) molecules that it assembles, such as proteins, carbohydrates, lipids, and nucleic acids.

CELL BIOLOGY (CONTINUED)	
8.	Demonstrate that most cells function best within a narrow range of temperature and pH; extreme changes usually harm cells by modifying the structure of their macromolecules and, therefore, some of their functions.
9.	Explain that a complex network of proteins provides organization and shape to cells.
10.	Explain that complex interactions among the different kinds of molecules in the cell cause distinct cycles of activities, such as growth and division.
11.	Describe that all growth and development of organisms is a consequence of an increase in cell number, size, and/or products.
12.	Explain how cell activity in a multicellular plant or animal can be affected by molecules from other parts of the organism.
13.	Explain why communication and/or interaction are required between cells to coordinate their diverse activities.
14.	Recognize and describe that cellular respiration is important for the production of adenosine triphosphate (ATP), which is the basic energy source for cell metabolism.
15.	Differentiate between the functions of mitosis and meiosis. Mitosis is a process by which a cell divides into each of two daughter cells, each of which has the same number of chromosomes as the original cell. Meiosis is a process of cell division in organisms that reproduce sexually, during which the nucleus divides eventually into four nuclei, each of which contains half the usual number of chromosomes.
16.	Explain how zygotes are produced in the fertilization process.
17.	Describe that all organisms begin their life cycles as a single cell, and in multicellular organisms the products of mitosis of the original zygote form the embryonic body.
Examples	*After viewing real-life images of prokaryotic cells (e.g., bacteria) and eukaryotic cells (e.g., amoeba, euglena, and paramecium) enacting life processes, students complete a Venn diagram that compares prokaryotes and eukaryotes (information is available at www.protistpark.com) (B.3.1).* *Students observe specialized cells such as bone, blood, muscle, and nerve cells under a microscope. They sketch their observations, pointing out similarities and differences among the cells and discussing how and why their bodies make specialized cells, even though cell contain the same genetic information (B.3.1).* *Students determine the effects in a cell if one of the organelles is removed. They determine the kinds of cell processes that had to be present and operational before those organelles could have evolved (B.3.2).* *Students create cell models to include the organelles responsible for transport, energy transformation, protein synthesis, waste removal, and motion (B.3.3).* *Students observe microscopic slides of plant and animal cells, then sketch and label their observations, highlighting the features unique to each cell (B.3.4).* *Students subject chicken eggs (which are technically one cell) to various temperatures, as well as immersion over time in vinegar or bleach (B.3.8).*

CELL BIOLOGY (CONTINUED)

Students dissect a beef heart or other muscle tissue to observe the protein structure and function. Students observe the multilayered complexity of the individual protein tissues that layer to form the muscle (B.3.9).

Students detail the healing of a cut or wound to show how skin cells divide and reproduce (B.3.11).

Students trace the pathway of a pain or pleasure signal from one part of the body to the brain (B.3.12).

Students watch a short video on how the heart muscle cells contract simultaneously, and then discuss the necessity and complexity of cellular communication and interactions. They research how this is simulated artificially by a pacemaker (B.3.13).

Students observe animations of the processes of mitosis and meiosis and/or images of actual cells undergoing the process for comparison. They complete a Venn diagram for mitosis and meiosis (information is available at www.cellsalive.com) (B.3.15).

Students compare the anatomy and growth of zebrafish, chicken, and human embryos (information is available at www.exploratorium.edu/traits/more.html) (B.3.17).

GENETICS

B.4. Broad Concept: Genes are a set of instructions encoded in the DNA sequence of each organism that specify the sequence of amino acids in proteins characteristic of that organism. As a basis for understanding this concept,

Students:

1. Research and explain the genetic basis for Gregor Mendel's laws of segregation and independent assortment.
2. Describe how the discovery of the structure of DNA by James D. Watson and Francis Crick made it possible to interpret the genetic code on the basis of a nucleotide sequence. Know the important contribution of Rosalind Franklin's data to this discovery (i.e., the careful X-ray crystallography on DNA that provided Watson and Crick the clue they needed to build the correct structure).
3. Explain how hereditary information is passed from parents to offspring in the form of "genes," which are long stretches of DNA consisting of sequences of nucleotides. Explain that in eukaryotes, the genes are contained in chromosomes, which are bodies made up of DNA and various proteins.
4. Know every species has its own characteristic DNA sequence.
5. Explain the flow of information is usually from DNA to RNA, and then to protein.
6. Explain how the genetic information in DNA molecules provides the basic form of instructions for assembling protein molecules and that this mechanism is the same for all life forms.
7. Understand and describe how inserting, deleting, or substituting short stretches of DNA alters a gene. Recognize that changes (mutations) in the DNA sequence in or near a specific gene may (or may not) affect the sequence of amino acids in the encoded protein or the expression of the gene.
8. Explain the mechanisms of genetic mutations and chromosomal recombinations, and when and how they are passed on to offspring.

GENETICS (CONTINUED)	
9.	Understand and explain that specialization of cells is almost always due to different patterns of gene expression, rather than differences in the genes themselves.
10.	Explain how the sorting and recombination of genes in sexual reproduction result in a vast variety of potential allele combinations in the offspring of any two parents.
11.	Explain that genetic variation can occur from such processes as crossing over, jumping genes, and deletion and duplication of genes.
12.	Explain how the actions of genes, patterns of inheritance, and the reproduction of cells and organisms account for the continuity of life.
13.	Investigate and describe how a biological classification system that implies degrees of kinship between organisms or species can be deduced from the similarity of their nucleotide (DNA) or amino acids (protein) sequences. Know that such systems often match the completely independent classification systems based on anatomical similarities.

Examples

Students choose flowering plants and try to breed them for certain traits (B.4.1).

Students explain the many roles of DNA testing and debate its uses as evidence in criminal trials (B.4.2).

Students observe or arrange a karyotype by chromosome pair and evaluate the results (information is available at sps.k12.ar.us/massengale/karyotype_lab.htm) (B.4.3).

Students compare the Cytochrome-C protein sequences of an ape, a human, a dog, a cat, and a mouse (information is available at www.indiana.edu/~ensiweb/lessons/mol.bio.html) (B.4.5 and B.4.13).

Students simulate transcription and translation from gene to protein. Given a DNA sequence, students transcribe the DNA into mRNA. Using an amino acid decoder, students convert the mRNA code into an amino acid chain (B.4.6).

Students research a specific genetic disease, such as hemophilia or cystic fibrosis, or a chromosomal syndrome, such as Down's syndrome. They interview a doctor, nurse, or medical technician, who can speak about some advances in therapies for their patients (B.4.8).

Students use Mendel's classic pea plant traits to complete Punnet Squares for monohybrid dominant/recessive crosses, incomplete dominance crosses, sex-linked crosses, and di-hybrid crosses to observe sorting, recombination, and resulting genotypes and phenotypes of offspring (B.4.10).

Students investigate and evaluate the impact of the work of Barbara McClintock with corn (B.4.11).

BIOLOGICAL EVOLUTION

B.5. Broad Concept: Evolution and biodiversity are the result of genetic changes that occur in constantly changing environments. As a basis for understanding this concept,

Students:

1. Investigate and explain how molecular evidence reinforces and confirms the fossil, anatomical, behavioral, and embryological evidence for evolution, and provides additional detail about the sequence in which various lines of descent branched off from one another.

2. Explain how a large diversity of species increases the chance that at least some living things will survive in the face of large or even catastrophic changes in the environment.

3. Research and explain how natural selection provides a mechanism for evolution and leads to organisms that are optimally suited for survival in particular environments.

4. Explain that biological diversity, episodic speciation, and mass extinction are depicted in the fossil record, comparative anatomy, and other evidence.

5. Describe how life on Earth is thought to have begun as one or a few simple one-celled organisms about 3.5 billion years ago, and that during the first 2 billion years, only single-cell microorganisms existed. Know that, once cells with nuclei developed about a billion years ago, increasingly complex multicellular organisms could evolve.

6. Explain that prior to the theory first offered by Charles Darwin and Alfred Wallace, the universal belief was that all known species had been created *de novo* at about the same time and had remained unchanged.

7. Research and explain that Darwin argued that only biologically inherited characteristics could be passed on to offspring, and that some of these characteristics would be different from the average and advantageous in surviving and reproducing; over generations, accumulation of these inherited advantages would lead to a new species.

8. Explain Gregor Mendel's identification of what we now call "genes," how they are sorted in reproduction, and how this led to an understanding of the mechanism of heredity. Understand how the integration of his concept of heredity and the concept of natural selection has led to the modern model of speciation and evolution.

9. Explain how biological evolution is also supported by the discovery that the genetic code found in DNA is the same for almost all organisms.

10. Explain that evolution builds on what already exists, so the more variety there is, the more there can be in the future.

Examples

Students investigate the mutation rate of microbes, such as pneumonia or tuberculosis bacteria (B.5.2).

Students evaluate the microbe mutation observations by researching CDC efforts to contain emerging strains of microbes, such as the mumps, avian bird flu, tuberculosis, and pneumonia (B.5.3).

Students compare the anatomy of the humerus, radius, ulna, metacarpal, and phalange bones of a whale, human, bat, frog, and horse (B.5.4).

Using register tape, students create a scaled timeline (e.g., 1 million years/centimeter) of the first life form to present-day organisms. They compare and contrast the lines of evidence for theories of dinosaur extinction (B.5.5).

BIOLOGICAL EVOLUTION (CONTINUED)

Students watch the Biography of Charles Darwin on A&E. They compare the works of Wallace and Darwin and discuss the contemporary set of beliefs, values, and opinions regarding speciation (B.5.6).

Students compare the evolution of the beaks of the finches on each geographically isolated island in the Galapagos to the type of seed or feeding the different finches use (B.5.7).

Students evaluate the tendency of life to introduce and support variety by examining the major extinctions and the numerous species that evolved even after 99 percent of life went extinct in those periods (B.5.10).

PLANT BIOLOGY

B.6. Broad Concept: Plants are essential to animal life on Earth. As a basis for understanding this concept,

Students:

1. Describe the structure and function of roots, leaves, flowers, and stems of plants.
2. Identify the roles of plants in the ecosystem: Plants make food and oxygen, provide habitats for animals, make and preserve soil, and provide thousands of useful products for people (e.g., energy, medicines, paper, resins).
3. Know that about 250,000 species of flowering plants have been identified.
4. Explain the photosynthesis process: Plants make simple sugars and other molecules in their leaves, and chlorophyll found in the leaves can make the food and nutrients that the plant can use from carbon dioxide, water, nutrients, and energy from sunlight.
5. Explain that during the process of photosynthesis, plants release oxygen into the air.
6. Describe that plants have broad patterns of behavior that have evolved to ensure reproductive success, including co-evolution with animals that distribute a plant's pollen and seeds.
7. Recognize that plants have a greater problem with "unpredictable environments" because they cannot seek shelter as many animals can.

Examples

Students research common medicines to determine the sources for those drugs (B.6.2).

Students visit the U.S. Botanical Garden or the National Arboretum to observe local and exotic plant life (B.6.3).

Students work in small groups to investigate the effects of several variables (e.g., nutrients, light, color of container) on oxygen production in aquatic plants growing in containers (B.6.4).

Students investigate "green architecture" for homes and larger office buildings, which adds plants inside and outside to promote CO_2 use and production of O_2 (information is available at www.sustainableabc.com) (B.6.5).

Students create a mathematical model for the travel of seeds. They begin with a small garden, research the number of seeds the plants can produce, and extrapolate the spread of the plant over 10, 100, and 1,000 years (B.6.6).

THE MAMMALIAN BODY

B.7. Broad Concept: As a result of the coordinated structures and functions of organ systems, the internal environment of the mammalian body remains relatively stable (homeostatic), despite changes in the outside environment. As a basis for understanding this concept,

Students:

1. Explain the major systems of the mammalian body (digestive, respiratory, reproductive, circulatory, excretory, nervous, endocrine, integumentary, immune, skeletal, and muscular) and how they interact with each other.
2. Analyze the complementary activity of major body systems, such as how the respiratory and circulatory systems provide cells with oxygen and nutrients, and remove toxic waste products such as carbon dioxide.
3. Explain how the nervous system mediates communication between different parts of the body and the environment.
4. Describe that the nervous and endocrine systems maintain overall regulation of optimal conditions within the body by chemical communication.
5. Investigate and cite specific examples of how the mammalian immune system is designed to protect against microscopic organisms and foreign (or non-self) substances from outside the body and against some aberrant (e.g., cancer) cells that arise within.

Examples

Students examine simpler bacteria and protist anatomy, and propose the metabolic processes or structures that needed to be present before mammalian anatomy could come to exist and function (B.7.1).

Students explain the body systems that are involved in sneezes and tears, or what happens when people laugh, and they review current explanations of physiologists, neurologists, and other experts of the physiology behind such phenomena (B.7.2).

Students diagram a reflex arc and complete several simple "reflex" activities, such as catching a ruler as it is dropped, classic "knee-jerk" reflex response, etc. (B.7.3).

Students research the sensation of normal skin nerve endings with the impaired nerve ending damaged by fire or severe burns (information is available at faculty.washington.edu/chudler/chmodel.html) (B.7.3).

Students evaluate the claims and risks of steroid use and apply the scientific evidence to a reported incidence of steroid use in an athlete (B.7.4).

ECOSYSTEMS

B.8. Broad Concept: Stability in an ecosystem is a balance between competing effects. As a basis for understanding this concept,

Students:

1. Illustrate and describe the cycles of biotic and abiotic factors (matter, nutrients, energy) in an ecosystem.
2. Describe how factors in an ecosystem, such as the availability of energy, water, oxygen, and minerals, and the ability to recycle the residue of dead organic materials, cause fluctuations in population sizes.

ECOSYSTEMS (CONTINUED)	
3.	Explore and explain how changes in population size have an impact on the ecological balance of a community and how to analyze the effects.
4.	Describe how the physical or chemical environment may influence the rate, extent, and nature of the way organisms develop within ecosystems.
5.	Describe how ecosystems can be reasonably stable over hundreds or thousands of years.
6.	Explain that ecosystems tend to have cyclic fluctuations around a state of rough equilibrium, and change results from shifts in climate, natural causes, human activity, or when a new species or non-native species appears.
7.	Explain how layers of energy-rich organic material, mostly of plant origin, have been gradually turned into great coal beds and oil pools by the pressure of the overlying Earth and its internal heat.
8.	Using ecological studies, explain distinct relationships and differences between urban environments and other environmental systems.
9.	Investigate and describe how point and non-point source pollution can affect the health of a bay's watershed and wetlands.
10.	Assess the method for monitoring and safeguarding water quality, including local waterways such as the Anacostia and Potomac rivers, and know that macroinvertebrates can be early warning signs of decreasing water quality.
Examples	*Students develop a "travel" brochure that describes the pathway of a carbon dioxide molecule and an oxygen molecule through the living and nonliving components of the biosphere (B.8.1).* *Students identify a pest in a local setting, and then compare and contrast the risks and benefits of chemical and biological pest control (B.8.4).* *Students research and share information on the origins and impacts of invasive species on the Chesapeake Bay. They include solutions to any problems that have been discovered (information is available at www.mdsg.umd.edu/exotics) (B.8.6).* *Students map oil fields and/or coal beds with rich fossil finds in the world (B.8.7).* *Students research EPA data on water pollution in their watershed (information is available at cfpub.epa.gov/surf/locate/index.cfm) (B.8.9 and B.8.10).*